Indian Journal of Engineering

ANALYSIS

ISSN 2319 – 7757 EISSN 2319 –7765

Investigations on the surface roughness of drilled hole on carbon fiber reinforced plastic composite

Publication History
Received: 29 April 2016
Accepted: 26 May 2016
Published: 1 July 2016

Citation
Ravi Sankar B, Umamaheswarrao P. Investigations on the surface roughness of drilled hole on carbon fiber reinforced plastic composite. *Indian Journal of Engineering*, 2016, 13(33), 415-421

INVESTIGATIONS ON THE SURFACE ROUGHNESS OF DRILLED HOLE ON CARBON FIBER REINFORCED PLASTIC COMPOSITE

B. Ravi Sankar*, P. Umamaheswarrao
Department of Mechanical Engineering, Bapatla Engineering College, Bapatla A.P, India. Pin-522102
***Corresponding author E-mail: ravinano@gmail.com**

Abstract

The present work aims to analyze the drilling parameters namely speed, feed and point angle for surface roughness of drilled hole on carbon fiber reinforced plastic (CFRP) composite. Three factors, three levels, Box Behnken design matrix is deployed to minimize number of experiments. Response Surface Method is adopted to develop mathematical model. The adequacy of the developed model is checked by using Analysis of Variance method technique. By using the developed mathematical model, surface roughness of the drilled CFRP composites are predicted with 95% confidence level. The influence of parameters on surface roughness is predicted from main effects plot and interaction effect plot and optimum parameters for minimum surface roughness are presented.

Keywords: Drilling, CFRP composite, surface roughness, ANOVA

1. INTRODUCTION

The utilization of natural fiber as a reinforced material can be traced back more than 10,000 years ago (Mwaikambo, L., 2006; Madsen, B., et al 2007) However, its applications in manufacturing industries gradually was replaced by synthetic fiber like glass, carbon and aramid fiber. These composite performance characters such as strength– weight ratios and modulus–weight ratios are markedly superior to those of metallic materials, and natural fiber reinforced composite. For these reasons, synthetic fiber reinforced polymers have emerged as a major class of structural materials and are widely used as substitution for metals in many weights critical components in aircraft, aerospace, automotive, marine and other industries (Mallick, P.K., 2008). Carbon fiber reinforced plastic (CFRP) composite materials found sundry applications in aerospace industries, automobile, sporting goods, marine, naval, space, machine tools, transportation structures, post strengthening of concrete beams and strengthening masonry shear walls in seismically active regions due to their static, dynamic, thermal and chemical properties. CFRP composites can be used effectively to improve the performance of structural members such as its load carrying capacity, stiffness, ductility, performance under cyclic loading, as well as environmental durability (Motavalli, M. and Flueler, P. 1998). Drilling is the most frequently employed operation of secondary machining for CFRP composites owing to the need for joining structures. However matrix cratering and thermal alterations, fiber pullout and fuzzing were observed to be the severe hindrances posed during drilling because of severe thrust forces developed, in homogeneity and anisotropic nature leading to 60% rejections (Abrate S. 1997). Eshetu D. Eneyew and Mamidala Ramulu (2014) investigated the drilling of unidirectional carbon fiber reinforced plastic (UD-CFRP) composite by using polycrystalline diamond (PCD) tipped eight facet drills. The quality of the drilled hole surface was examined through surface

roughness measurements and surface damage by scanning electron microscopy (SEM). The authors found that fiber pullout occurred in two specific sectors relative to the angle between the cutting direction and the fiber orientation. C.C. Tsao and H. Hocheng (2008) predicted surface roughness in drilling of composite material using candle stick drill. The experimental results revealed that the feed rate and the drill diameter were the most significant factors affecting the thrust force, while the feed rate and spindle speed contribute the most to the surface roughness. Hamzeh Shahrajabian and Masoud Farahnakian (2013) observed the influence of drilling parameters on surface roughness of the drilled hole on CFRP composite and reported that there exists optimum set of parameters which will lead minimum surface roughness.

From the existing literature it is evident that the Composites are difficult machining materials which widely used in aerospace industry due to their excellent mechanical properties. Tool wear and delamination are considered the major concern in manufacture the parts and assembly. The thrust force and torque affect the tool life and delamination mostly. Numerous studies reported the influence of various process parameters on thrust force, however few works are available addressing the surface roughness of drilled hole on CFRP composite. Hence the present work is aimed to investigate the effect of speed, feed and point angle on surface roughness of drilled hole on CFRP composite. The experiments are carried out under air cooling cutting conditions and the regulation of the surface roughness influenced by the speed, feed rate and point angle is presented.

2. EXPERIMENTAL PROCEDURE

2.1 Material and Machine Tool

The material used in drilling is CFRP composite material plain woven bidirectional with 50% (typical values for fiber fractions in polymer composites ranges in 30-55% (Department of Defense, 2002) woven carbon fiber in weight with an orientation of 0/90 matrix using autoclave molding. Autoclave molding is the process of curing materials using relatively high heat and high pressure in a vessel. In the present work the composite is cured at a pressure of 2MPa and a temperature of 200°C. The atmosphere within the vessel is purged of oxygen using nitrogen, to displace the oxygen thereby preventing thermal combustion of the materials being cured. The composite material, with 6±0.1 mm thickness in 28 layers had a 55% cured fiber volume fraction. The work piece material is cut in the size of a 60mm×60mm sheet. Drilling tests are performed on a Radial drilling machine (Make: Energy machine tools pvt. Ltd.) and Surface roughness of machined holes, represented by the parameter Ra, was measured by PERTHOMETER M2 (Mahr, Germany) instrument. The drilled CFRP composite is shown in Fig.2.

2.2 Experimental Details

An experiment is a series of trials or tests, which produces quantifiable outcomes due to slightly wide ranges of the factors. Design of experiment is found to be a powerful tool for modeling and analysing the influence of process parameters over the response with minimum number of experiments. Box Behnken design is found to be the most efficient tool in Response surface methodology (RSM) to establish mathematical relation of the response

surface using smallest possible number of experiments without losing accuracy (W.G.Cochran and G.M.Cox, 1957).

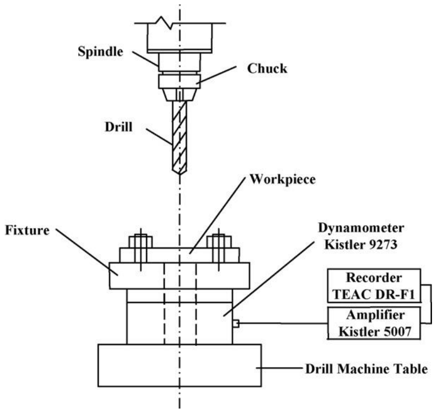

Fig. 1 Drilling Machine setup

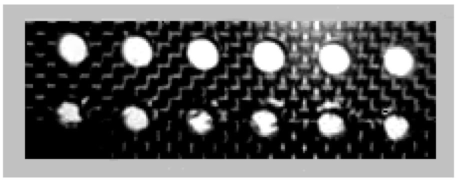

Fig. 2 Photograph of drilled composite

To explore the relationship between the response and the independent variables, the data required are obtained experimentally. The selected parameters and their levels are shown in Table 1. The experimental matrix is developed for three factors and three level based on Box Behnken design which consists of fifteen trails. The experimental matrix along with results is shown in Table 2.

2.3 Developing Mathematical Model

The ultimate surface roughness of the drilled CFRP composite material is a function of Speed (A), Feed (B) and Point angle (C). The relation between input parameters and the response can be obtained using RSM (W.G.Cochran and G.M.Cox, 1957). The Surface Roughness is expressed as

Surface Roughness (R_a)

$$R_a = f(A,B,C) \quad (1)$$

The model chosen is a second degree response to check the nonlinearity and is expressed as (Montgomery D.C 1991):

$$Y=\beta_0+ \beta_1 (A) + \beta_2 (B) + \beta_3 (C) +\beta_4 (A^2) + \beta_5 (B^2) +\beta_6 (C^2) + \beta_7 (AB) +\beta_8 (AC) +\beta_9 (BC) \quad (2)$$

Using MINITAB 14 statistical software package, the significant regression coefficients are determined for 95% confidence level and the final models are developed to estimate Surface Roughness. Details about estimated regression coefficients for Surface Roughness are presented in Table 3. The value of co-efficient of determination 'R^2' for the above developed model is found to be about 99.8%.

Table 1 Factors and their levels

S. No	Parameter	Notation	Unit	Levels		
				-1	0	1
1.	Speed, N	A	rpm	1000	1500	3000
2.	Feed, F	B	mm/min	50	325	600
3.	Point angle, Φ	C	degree	60	100	140

Table 2 Experimental matrix with results

S.NO	Speed (N)	Feed (f)	Point Angle (Φ)	Surface Roughness (Ra)
1.	1250	50	100	0.939
2.	4000	50	100	0.953
3.	1250	800	100	2.542
4.	4000	800	100	1.998
5.	1250	425	60	1.293
6.	4000	425	60	1.224
7.	1250	425	140	1.336
8.	4000	425	140	1.144
9.	2625	50	60	0.711
10.	2625	800	60	1.72
11.	2625	50	140	0.74
12.	2625	800	140	1.717
13.	2625	425	100	1.135
14.	2625	425	100	1.6
15.	2625	425	100	1.125

Table 3 Estimated Regression Coefficients for Surface Roughness

Term	Coef	SE Coef	T	P	
Constant	0.864335	0.159221	5.429	0.003	Significant
N	-0.000387	0.000059	-6.572	0.001	Significant
f	0.000485	0.000177	2.743	0.041	Significant
Φ	0.007233	0.002367	3.055	0.028	Significant
N*N	0.000000	0.000000	8.728	0.000	Significant
f*f	0.000001	0.000000	9.611	0.000	Significant
Φ*Φ	-0.000036	0.000011	-3.334	0.021	Significant
N*f	-0.000000	0.000000	-1.475	0.200	Insignificant
N*Φ	-0.000000	0.000000	-0.045	0.966	Insignificant
f*Φ	0.000000	0.000001	0.271	0.797	Insignificant

S = 0.03322 R-Sq = 99.8% R-Sq(adj) = 99.4%

The final mathematical model is given by Surface Roughness (R_a)

$$R_a = -0.000387A+0.000485B+0.007233C+0.000001B^2-0.000036C^2+0.864335 \quad (3)$$

Where A, B and C are the coded values of speed, feed and point angle.

2.4 Checking the Adequacy of the Developed Model

The adequacy of the developed model is tested using the Analysis of Variance technique (ANOVA). As per this technique, if the calculated value of F_{ratio} of the developed model is less than the standard F_{ratio} (from F-table) value at a desired level of confidence (say 95%), then the model is said to be adequate within the specified confidence limit. ANOVA test results presented in Table 4 are found to be adequate at 95% confidence level.

Table 4 ANOVA test results of Surface Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	2.38918	2.389177	0.265464	240.62	0.000
Linear	3	2.18991	0.082745	0.027582	25.00	0.002
Square	3	0.19679	0.196786	0.065595	59.46	0.000
Interaction	3	0.00248	0.002484	0.000828	0.75	0.567
Residual Error	5	0.00552	0.005516	0.001103		
Lack-of-Fit	3	0.00551	0.005514	0.001838	1838.08	0.001
Pure Error	2	0.00000	0.000002	0.000001		
Total	14	2.39469				

3. RESULTS AND DISCUSSIONS

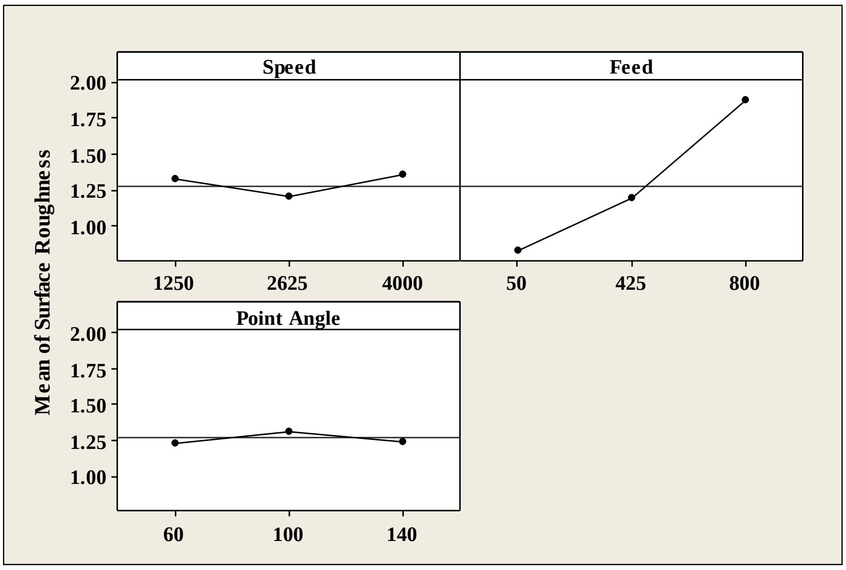

Fig. 3 Main effects plot for surface Roughness

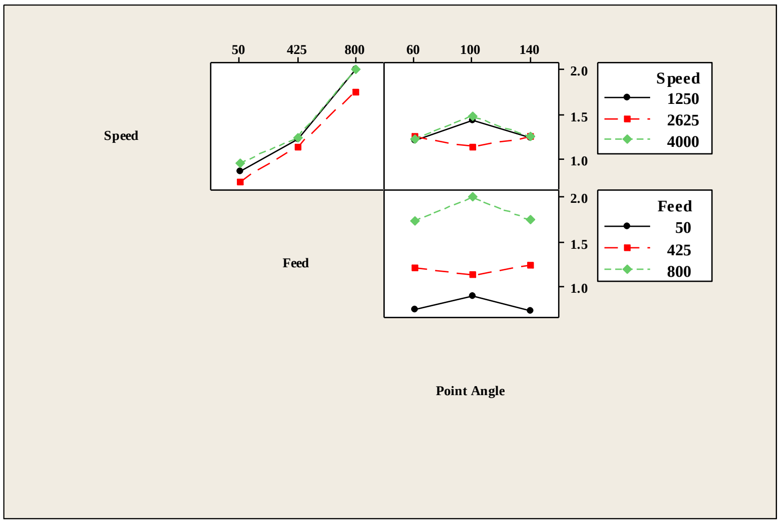

Fig. 4 Interaction plot for surface Roughness

The above developed mathematical model can be employed to predict the surface roughness and their relationship for the range of parameters used in the investigation by substituting their respective values in the coded form. Based on these models, effects of the process parameters on the surface roughness is computed and plotted, as depicted in Fig.3. The main

effects plot (Fig.3) demonstrates that the surface roughness is decreased from 1250 rpm of speed to 2625 rpm and thereafter it increases, steeply incrementing with feed rate and slightly increases and then decreases with point angle.

From the interaction effects plot (Fig.4), it can be understood that the surface roughness value is significantly augmented with the interaction between speed and feed. The interaction of speed and point angle results in increasing and decreasing trend for extreme limits of feed rates, however it is in vice-versa for intermediate value. The similar trend is observed for the interaction of feed and point angle with speed.

CONCLUSIONS

An investigative analysis of parametric influence on surface roughness in drilling of carbon fiber reinforced plastic (CFRP) composites has been presented in this paper. The surface roughness is studied with respect to cutting speed, feed rate and point angle by developing a second order regression model. The database required to construct the model is obtained by conducting drilling experiments planned as per Box Behnken response surface design. The developed model is validated through analysis of variance (ANOVA). The influence of selected process parameters on surface roughness is analyzed and found that the surface roughness is optimum at a speed of 2625 rpm, feed of 50 and at a point angle of 140.

REFERENCES

Abrate S., (1997), *Machining of Composites*, *Composites engineering hand book*, Marcel Deckker Inc: New York.

Department of Defense (2002), *Composite Materials Handbook*, Volume 3 of 5.

Eshetu D. Eneyew and Mamidala Ramulu (2014), Experimental study of surface quality and damage when drilling unidirectional CFRP composites, *Journal of materials research technology*, 3(4), 354–362.

Hamzeh Shahrajabian and Masoud Farahnakian (2013), Modeling and Multi-Constrained Optimization in Drilling Process of Carbon Fiber Reinforced Epoxy Composite, *International Journal of Precision Engineering and manufacturing*, 14(10), 1829-1837.

Palanikumar, K., (2007), Modeling and analysis for surface roughness in machining glass fibre reinforced plastics using response surface methodology, *Materials and Design*, 28, 2611–2618.

Madsen, B., (2007), Hemp yarn reinforced composites–I. Yarn characteristics, *Composites Part A: Applied Science and Manufacturing*, 38(10), 2194-2203.

Mallick, P.K., (2008), *Fiber Reinforced Composite - Materials, Manufacturing and Design,* CRC Press and Taylor & Francis Group: Boca Raton.

Montgomery D.C., (1991), *Design and analysis of experiments*. John Wiley & sons: New York.

Motavalli, M. and Flueler, P. (1998), Characterization of unidirectional carbon fibre A reinforced plastic laminates, *Materials and structures*, 31(3), 178-180.

Mwaikambo, L. (2006), Review of the history, properties and application of plant fibres, *African Journal of Science and Technology*, 7(2), 120-133.

W.G.Cochran and G.M.Cox (1957), *Experimental designs*. John Wiley & Sons: New York.

